Using price and demand information to identify production functions

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Abstract

This paper explores the use of information on the firm-level prices of the produced output and employed inputs, as well as on the firm-level demand relationship, to identify the parameters of the production function. By considering the system of equations which includes the demands for variable inputs, the demand for the product of the firm and the pricing rule, both the production function and the cost equation can be rewritten in terms of fixed inputs and exogenous determinants (semi-reduced forms). Consistent estimation of this two equation system is possible under no especial distribution assumptions on unobserved efficiency and, in addition, an estimate of the price elasticity of demand is recovered.

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1.Introduction

Estimation of microeconomic production functions has proved a hard task because of the simultaneous determination of output and relevant inputs by the same forces. The main consequence is that chosen input quantities are correlated with the unobservable productivity level which characterizes the firm-specific production function, which is likely to evolve over time as affected by productivity shocks This unobservability creates also eventually a selectivity problem: firms with the worst productivity performance may be induced to leave the market. The problem of simultaneous determination of inputs and output, as well as the relevance of the simultaneous equations framework for dealing with this setting, was first pointed out by Marschak and Andrews (1944). Griliches and Mairesse (1998) revise the economists' motivation and efforts for developing estimation methods robust to simultaneity and contributions have not ceased (see Ackerberg, Benkard, Berry and Pakes (2005) for a revision of recent.proposals).

Two methods have dominated the most recent approaches to consistent estimation under simultaneity. One stresses the equation transformations under which the unobserved efficiency levels of the production relationship are likely to disappear, or being reduced to limited forms of residual correlation, and proposes the use of suitable instruments orthogonal to the remaining disturbances to obtain identification. Panel "fixed effects" and the estimation of equations in first differences belong to this tradition. Blundell and Bond (2000), for example, argue that the standard panel first-differences GMM estimators are likely to present large finite-sample biases due to the time series persistence properties of some of the involved variables. They propose exploiting additional instruments in an extended GMM estimator which includes level moments. The other approach proposes semiparametric methods to control for (Markovian) correlated productivity terms, based on the observability of the investment (or input choice) decisions of the firms. With unobserved efficciency adequately controlled for, correlation of input quantities ceases to be a problem. Olley and Pakes (1996) first proposed this method, which has been followed by Levinsohn and Petrin (2002) and many others.

This paper is aimed at exploring the use of information on the firm-level prices and the demand relationship to identify the parameters of the production function. In the previously described context it takes seriously the often quoted reference of Griliches that addressing the simultaneity problem is harder "without constructing a complete production and input decision behavior model." We draw on the idea first discussed in Griliches and Mairesse (1984) about how to deal with the simulaneity-induced problems by using semi-reduced or reduced forms of the relevant economic system. But we enlarge the model by considering that firms compete in an imperfectly competitive environment, and that price must therefore be taken as an additional endogenous variable simultaneously set by the firm. By considering the suitable system of equations, which includes input demand relationships, the demand for the product of the firm, and the pricing rule, we show that both the production function and an (average) cost equation can be rewritten in terms of exogenous determinants in addition of the fixed factors (semi-reduced forms) and used to estimate the relevant parameters.

If firms were perfectly competitive, the production function (with short run decreasing returns to scale) combined with equations of demand for variable inputs, depending on output quantity and output and input prices, is all what is needed to obtain a set of semi-reduced form equations in which variable factors depend only on fixed factor quantities and exogenous prices. And these relationships can be substituted for in turn in the production function to explain output. But, when firms must be taken as having some market power (represented by a somewhat downward slooping firm-specific relationship), price becomes an endogenous variable set with a markup on marginal cost (which inherits through duality all unobserved efficiency that production function may have) according to the state of competition. We then enlarge the previous system by adding a firm-specific demand relationship, which depends on unobserved demand advantages but also on observed demand shifters and price, as well as the firm pricing rule. The pricing rule specifies price as a function of marginal cost and takes into account possible changes in competition. Using this system, the demands for factors can be again written in terms of fixed inputs, exogenous input prices and the demand shifters. These relationships can be again substituted for in the production function. We then show that a two equation system for output and cost can be used to identify simultaneously the production function parameters and the elasticity of demand with respect to price. Imperfect competition hence raises a more complex system, but also gives a natural and theoretically sound role for the use of demand shifters in the identification of the production function. This method has the important advantage that does not rely on specific distributional assumptions about unobserved efficiency and other noises. The main disadvantage is, however, the high requirements on firm-specific information.

Using a rich data set, consisting of (unbalanced) observations on more than 1,400 Spanish manufacturing firms during the period 1990-1999, we present preliminary production function estimates. Information on firms include firm-level variations for the price of the output and the price of the inputs, technological (process and product) innovations, as well as additional demand shifters. We report and comment the estimates obtained with conventional OLS and IV estimators, as well as the results of applying different estimators to semi-reduced forms.

The rest of the paper is organised as follows. Section 2 explains the theoretical framework and derives the semi-reduced forms and the meaning of the coefficients. Section 3 explains the data and the econometric specification. Section 4 presents preliminary estimates and Section 5 concludes. An Appendix provides some detail on the sample, the employed variables and computes descriptive statistics.

2. A reduced form system

We assume that firms have production functions of the form $Q = \theta_1 F(\overline{X}, X)$, where Q represents output, $\overline{X}$ stands for a vector of fixed inputs, X for variable inputs and θ_1 is the productivity level reached by the firm (we drop firm and time subindices for simplicity). We assume that the production function is (perhaps locally) homogeneous of degree μ, the sum of the elasticities of the variable inputs. Productivity levels are Hicks neutral and firm-idiosyncratic. They are observed only by the firm and evolve over time. Firms choose simultaneously Q and X and we assume, without loss of generality, that firms choose X in order to minimize costs given θ_1. In what follows we specify how firms determine Q.

Firms' demand for its product[1] is given by a firm-specific demand function of the form $Q = \theta_2 Q(Z, P)$, where Z is a vector of demand shifters and P is the price of the product set by the firm. Idiosyncratic demand terms θ_2 reflect persistent demand advantages and firm-specific demand shocks, both observed only by the firm. Demand shifters may be either exogenously driven (e.g. state of the market) or reflect firm previous investments (e.g. advertising). The elasticity of demand with respect to P must be understood in net terms, i.e. given the game firms play in the market, and, in fully competitive situations, may tend to (minus) infinity. We assume P is the result of firms pricing according to the rule $P = (1 + m)C'$, where C' stands for (short-run) marginal cost and m is the makup which results from the particular game firms play.

Firms set prices and variable input quantities are chosen according to the output to be produced and productivity (given input prices), and hence are endogenous in the production function relationship (i.e. they are correlated with the unobserved term θ_1). However, consideration of the way the firm sets price, and hence output, brings in a natural set of structural exogenous determinants for output, and hence inputs, which can be used, together with input prices, to write a reduced form equation for output. Additionally, production function has an associated cost function in which output is endogenous (the productivity term transforms in a lower cost term). Exogenous determinants for output can be used similarly to obtain a reduced form equation for cost. Both reduced form equations (output and cost) can be used to identify the production function parameters. This is shown in what follows.

We are going to set our model in terms of growth rates, log-differencing the involved equations. This has at least two advantages. Firstly, we can then use in the analysis some variables which are available only in terms of growth (e.g. price growth rates, which correspond to price indices whose levels have no economic content). Secondly, we can deal more safely with a high degree of heterogeneity. Firm-specific unobservable effects are

[1] We assume that there is some product differentiation among the firms which compete in a given market.

differenced out and equations in terms of growth rates may be thought of as approximating general functional forms. On the other hand, an important problem has been attributed to the employment of differences in the contex of highly persistent data (see, for example, Blundell and Bond, 2000) : the lack of correlation between current growth rates and past levels of the variables may seriously bias IV estimators. But this lack of correlation can be just seen as a third advantage in our contex. As we are going to use exclusively rates of change of exogenous and predetermined variables as regressors, we can expect no correlation between regressors and errors even with serially correlated residuals.

Write u_1 for the disturbance resulting from the log-differentiation of the production function. Assuming that there are R and J fixed and variable factors respectively, log-differencing the production function then gives

$$q = \sum_r \varepsilon_r \overline{x}_r + \sum_j \varepsilon_j x_j + u_1 \tag{1}$$

where small letters stand for growth rates.

According to the most standard assumptions in the specification of production functions the term u_1 can be: a) a serially uncorrelated disturbance, because θ_1 is the exponential of a random walk (i.e. $\theta_{1t} = \exp(\omega_{1t})$, with $\omega_{1t} = \omega_{1t-1} + u_{1t}$); b) a disturbance presenting a limited serial correlation, because θ_1 has two components, a “fixed” one which remains unchanged over time and a time varying uncorrelated shock (e.g. $\theta_{1t} = \exp(\omega_1 + \epsilon_{1t})$ with $\epsilon_{1t} \sim MA(0)$ and hence $u_{1t} = (\epsilon_{1t} - \epsilon_{1t-1}) \sim MA(1)$); c) a serially correlated disturbance because θ_1 is either the exponential of a Markov process (i.e. $\theta_{1t} = \exp(\omega_{1t})$, with $\omega_{1t} = \rho\omega_{1t-1} + \epsilon_{1t}$ and hence $u_{1t} = \omega_{1t} - \omega_{1t-1} = -(1-\rho)\omega_{t-1} + \epsilon_{1t}$) or a combination of this and an $MA(0)$ disturbance. We do not need to make any distributional assumption at this stage. We therefore assume that u_1 is a distributionally unspecified disturbance potentially correlated with the input choices.

First order conditions of cost minimization for each variable input are given by $C' \frac{\partial F}{\partial x_j} = w_j$, which can also be manipulated to obtain the cost-share/input-elasticities equality $\frac{w_j x_j}{(C/Q)Q} = \frac{\varepsilon_j}{\mu}$. Log-differencing these conditions, writing c for the rate of growth of average variable-cost ($c = \frac{d(C/Q)}{C/Q}$) we obtain the relationships

$$x_j = q - (w_j - c) \tag{2}$$

Endogeneity of x_j in equation [1] must be understood as the effect of its determination through the q and c values. A disturbance term (optimization error), uncorrelated with the included variables, could be added meaningfully to each one of these J relationships without any substantial change in what follows. We avoid it for simplicity of notation.

Under cost minimization, the production function has an associated variable-cost function of the form $C(w, Q, \overline{X}) = C(w, \overline{X})(Q/\theta_1)^{1/\mu}$, from which we can obtain the log-differenced average cost function which follows

$$c = -\frac{1}{\mu}\sum_r \varepsilon_r \overline{x}_r + \frac{1}{\mu}\sum_j \varepsilon_j w_j + (\frac{1}{\mu} - 1)q - \frac{u_1}{\mu} \tag{3}$$

Assume now that log differences of θ_2 give a disturbance u_2, with similar properties to the ones of u_1, and possibly correlated with it. Log-differentiation of demand gives then the relationship

$$q = z - \eta p + u_2 \tag{4}$$

where η stands for the elasticity of demand with respect to the product price. And, at the same time, the log differences of the pricing rule can be written as

$$p = \Delta m + c \tag{5}$$

where Δm stands for the markup differences. Again, a disturbance term could be added meaningfully to this relationship without any substantial change in what follows.

Now we are ready to use the system of equations (1)-(5) to obtain reduced forms for q and c respectively. Firstly, use (5) and (4) to express c in terms of q, the demand shifters and margin changes. Then, replace the c which appears in [2] by this expression. Each input change can be written as $x_j = (1 - \frac{1}{\eta})\ q - w_j + \frac{z}{\eta} - \Delta m + \frac{u_2}{\eta}$. It follows that

$$q = \sum_r \beta_r \overline{x}_r - \sum_j \beta_j w_j + \beta_z z - \beta_m \Delta m + v_1 \tag{6}$$

where $\beta_r = \frac{\varepsilon_r}{D}$, $\beta_j = \frac{\varepsilon_j}{D}$, $\beta_z = \frac{\mu}{\eta D}$, $\beta_m = \frac{\mu}{D}$, $D = 1 - (1 - \frac{1}{\eta})\mu$, and $v_1 = \frac{1}{D}u_1 + \frac{\mu}{\eta D}u_2$.

Similarly, p can be replaced in (4) using equation (5). Then we have output changes in term of demand shifters, margin changes and c, that is $q = z - \eta\Delta m - \eta c + u_2$. Substituting this for q in equation (3) we obtain

$$c = -\sum_r \delta_r \overline{x}_r + \sum_j \delta_j w_j + \delta_z z - \delta_m \Delta m + v_2 \tag{7}$$

where $\delta_r = \frac{\varepsilon_r}{\eta D}$, $\delta_j = \frac{\varepsilon_j}{\eta D}$, $\delta_z = \frac{1-\mu}{\eta D}$, $\delta_m = \frac{1-\mu}{D}$ and $v_2 = -\frac{1}{\eta D}u_1 + \frac{1-\mu}{\eta D}u_2$.

All explanatory variables of equations (6) and (7) can be considered either exogenous $(w, z, \Delta m)$ or predetermined $(\overline{x})$. Disturbances u_1 and u_2 are presumably correlated, and their structure depends on the properties of $\theta_1$and θ_2. In practice, estimated coefficients $\beta_z, \beta_m, \delta_z, \delta_m$ are likely to be affected by a problem of scale (we only have indicators of z and Δm), but coefficients $\beta_r, \beta_j, \delta_r, \delta_j$ allow for the identification of the production function (and demand) parameters. Parameters of the two equations are subject to the following relationships: $\eta = \frac{\beta_r}{\delta_r} = \frac{\beta_j}{\delta_j}$, and $\mu = \frac{\eta \sum \beta_j}{\eta + (\eta - 1)\sum \beta_j}$, $\varepsilon_j = \frac{\eta \beta_j}{\eta + (\eta - 1)\sum \beta_j}$, $\varepsilon_r = \frac{\eta \beta r}{\eta + (\eta - 1)\sum \beta_j}$ or, in terms of the δ parameters, $\mu = \frac{\eta \sum \delta_j}{1 + (\eta - 1)\sum \delta_j}$, $\varepsilon_j = \frac{\eta \delta_j}{1 + (\eta - 1)\sum \delta_j}$ and $\varepsilon_r = \frac{\eta \delta r}{1 + (\eta - 1)\sum \delta_j}$. Long run elasticity of scale is $\sum \varepsilon_r + \sum \varepsilon_j$. The structure of the elasticities is identified in each equation, but total short and long run elasticities can be identified using both equation to obtain η.

3. Data and econometric specification

We present preliminary estimates based on an (unbalanced) sample with observations on more than 1,400 Spanish manufacturing firms during the period 1990-1998. All variables come from the information furnished by firms at the survey ESEE (Encuesta Sobre Estrategias Empresariales), a firm level panel survey of Spanish manufacturing starting in 1990. At the beginning of this survey, firms with fewer than 200 workers were sampled randomly by industry and size strata, retaining 5%, while firms with more than 200 workers were all requested to participate, and the positive answers represented more or less a self-selected 60%. To preserve representation, samples of newly created firms were added to the initial sample every subsequent year. At the same time there are exits from the sample, coming from both death and attrition. So, it can be considered a random sample of Spanish manufacturing with the largest firms oversampled. A Data Appendix provides details on the variables definition, sample composition, industry breakdown and gives descriptive statistics.

Information on the firms include, in addition to the usual output and input quantity measures, the firm-level variations for the price of the output and the price of the inputs, information about the introduction of technological (process and product) innovations, and some demand shifters. Specifically, we have first the usual variables output (deflated production), capital stock estimate, labor measured in total (effective) hours of work, intermediate consumption and the firm self reported utilization of the standard capacity of production. We deflate the nominal output measure (sales plus inventories) by firm-level individual prices but, alternatively, we also use a set of 114 industry indices[2]. In addition, we can compute variable cost as the sum of the wage bill and intermediate consumption, and estimate the hourly wage dividing the wage bill by total hours of work. But we also have some less usual firm-level variables which play a key role in our estimations. Firstly, we have the yearly (average) output price change as reported by the firm. Secondly, firms also provide an (average) estimate of the change in the cost of inputs grouped in three sets: energy, materials and services. Finally, we can compute a firm specific user cost of capital using the interest rate payed by the long-term debt of the firm plus the rough estimate of a 0.15 depreciation rate and minus the consumer prices index variation. We will use a cost shifter and three demand shifters. The cost shifter is the dummy representing the introduction of innovations. The three demand shifters are the dummy reporting the introduction of product innovations, the rate of increase of the firm advertising and an index of the dynamism of the firm specific market.

We specify the reduced form for output (6) including the fixed input capital k and the

[2] On the relative impact of deflation by means of different indices see Mairesse and Jaumandreu (2005).

prices of the variable inputs (wage, w, and materials, p_M) adding the demand and margin shifters (denoting i for the introduction of innovations, d for market dynamism and a for the growth rate of advertising) and utilization of capacity uc. We specify the reduced form for (average) cost (7) including the fixed input capital, the prices of the variable inputs (wage and materials) and the shifters.and utilization of capacity Our empirical equations system can then be written as

$$
\begin{aligned}
q &= \beta_0 + \beta_{pc} i_{pc} + \beta_k k + \beta_w w + \beta_M p_M + \beta_d d + \beta_a a + \beta_{pd} i_{pd} + \beta_{uc} uc + time + v_1 \\
c &= \delta_0 + \delta_{pc} i_{pc} + \delta_k k + \delta_w w + \delta_M p_M + \delta_d d + \delta_a a + \delta_{pd} i_{pd} + \delta_{uc} uc + time + v_2
\end{aligned}
$$

where $\beta_k = \frac{\varepsilon_k}{1-(1-\frac{1}{\eta})(\varepsilon_l+\varepsilon_M)}$, $\delta_k = -\frac{\varepsilon_k}{\eta\left[1-(1-\frac{1}{\eta})(\varepsilon_l+\varepsilon_M)\right]}$, $\beta_w = -\frac{\varepsilon_l}{1-(1-\frac{1}{\eta})(\varepsilon_l+\varepsilon_M)}$, $\delta_w = \frac{\varepsilon_l}{\eta\left[1-(1-\frac{1}{\eta})(\varepsilon_l+\varepsilon_M)\right]}$, $\beta_M = -\frac{\varepsilon_M}{1-(1-\frac{1}{\eta})(\varepsilon_l+\varepsilon_M)}$ and $\delta_M = \frac{\varepsilon_M}{\eta\left[1-(1-\frac{1}{\eta})(\varepsilon_l+\varepsilon_M)\right]}$.

So we have a two equation model, with nonlinear cross-restrictions in the parameters, which in principle can identify production elasticities, returns to scale and demand elasticity. Let us briefly state the properties of the specification. Firstly, under competitive factor markets and no measurement problems we can expect the input prices to be orthogonal to both equation errors, i.e. $E(wv) = 0$. Secondly, we can assume that the demand (and margin) shifters are by definition orthogonal to the primitive u_2 error of the demand equation, but probably it can be not assumed that they are not correlated to the unobserved effciency changes represented by the primitive error term u_1. This does not constitute a problem as long as we do not pretend estimate structural coeffcients on these shifters. That is, let $Z = (z, \Delta m)$, we expect $E(Zu_2) = 0$ by construction but perhaps $E(u_1|Z) \neq 0$ is likely and Z must be taken as simple controls (no structural coefficients on Z). Thirdly, both equations include the predetermined input capital that, with u_1 and u_2 autocorrelated and presumably inducing autocorrelation in v_1 and v_2, cannot be considered exogenous. That is, we expect $E(\overline{x}v) \neq 0$ and some instrument must be used at least for this variable. Fourthly, in practice, preliminary estimates show quickly that we are going to need to instrument also prices to obtain sensible coefficients. The reason is the errors that observed prices are likely to include with respect to prices relevant for the firm maximization problem. Even letting aside pure measurement problems, adjustment input costs make relevant unobserved "shadow" prices.

In practice, we are going to use three intruments that we can classify in two types. Firstly we use as natural instrument for k the user cost of capital.(r) Secondly, we try to solve for the need to predict the right "shadow" prices in the first equation by using the effective hours per worker (ehw) and a variable representing market-wide price decreases (mpv, which we assume correlated to materials price changes) to instrument for wages and the price of materials.respectively. So, our instrument sets can be written as $Z_1 = \{1, i_{pc}, d, a, i_{pd}, uc, time, ehw, mpv, r\}$ and $Z_2 = \{1, i_{pc}, d, a, i_{pd}, uc, time, w, p_M, r\}$.

We present estimates obtained with conventional OLS and IV estimators as well as the results of applying different estimators to reduced forms but the model fits most naturally in the non-linear GMM problem

$$\min_{\theta} \begin{bmatrix} \frac{1}{N}\sum_i Z_{1i}'v_{1i} \\ \frac{1}{N}\sum_i Z_{2i}'v_{2i} \end{bmatrix}' A \begin{bmatrix} \frac{1}{N}\sum_i Z_{1i}'v_{1i} \\ \frac{1}{N}\sum_i Z_{2i}'v_{2i} \end{bmatrix}$$

where Z_{ji} are $T_i \times k_j$, with $j = 1, 2$ and $i = 1...N$ and which can be implemented using a first step weighting matrix

$$A = \begin{bmatrix} (\frac{1}{N}\sum_i Z_{1i}'Z_{1i})^{-1} & 0 \\ 0 & (\frac{1}{N}\sum_i Z_{2i}'Z_{2i})^{-1} \end{bmatrix}$$

A robust variance estimate of the parameters can then be obtained by employing the formula $Var(\theta) = (\Gamma' A\Gamma)^{-1}\Gamma' AE(Z_i'v_iv_i'Z_i)A\Gamma(\Gamma' A\Gamma)^{-1}$, where $\Gamma = E(\frac{\partial(Z_i'v_i)}{\partial\theta})$ is estimable using $\frac{1}{N}\sum_i \frac{\partial(Z_i'\widehat{v}_i)}{\partial\theta}$ and $\frac{1}{N}\sum_i Z_i'\widehat{v}_i\widehat{v}_i'Z_i$.In practice the equations can be "concetrated out" for the estimation of parameters which enter linearly and the non-linear search is over $\varepsilon_k, \varepsilon_l, \varepsilon_M$ and η.

Some general comments on the specifications are in order. Firstly, we carry out all estimates in differences. Almost all non-dummy variables are then in log rates of change (the exceptions are the user cost of capital and the market dynamism index). There are at least three good reasons to do so: individual price information are in the form of rates of growth, the equations can then be considered approximations to general functional forms and, eventually, that the well known weak correlation betwen rates of growth and past levels of the variables enforces the credibility of our exogeneity assumptions. Secondly, time dummies are included in all equations with coefficients constrained to add up zero. Therefore, the constants of the equations reflect the "autonomous" average growth of the dependent variable. Thirdly, the impacts of the introduction of process and product innovations are picked up by dummies. After some experimenting, we decided that these dummies entered the equations always lagged one period (the main effects of innovations seem to take place with some lag; see Huergo and Jaumandreu, 2004).

4. Estimation results

In this section we briefly comment the estimates obtained using three approaches. Firstly, a direct conventional estimation of the production function, assuming a fixed input, capital, and two variable inputs, labour and materials Secondly, a separated estimation of both the output and cost reduced forms.We estimate each equation using OLS and IV. Thirdly, the non-linear GMM joint estimation of the system.

Table 1 reports the main results of the direct conventional production function estimates. Capital and utilization of capacity always tend to obtain close coefficients (a bit lower for capital) and we opt for reporting the results for the constrained variable (variation in) "used capital." OLS results are not bad. Capital attracts a statistically significant coefficient, although somewhat small: 19% of the sum of the capital and labour elasticities (see Value added elasticities). Returns to scale, as is usual in OLS estimates, turn out to be diminishing (elasticity of scale is less than 0.8). The use of different ways of deflating the output measure has a small impact on the estimates. It is worthy of noting that the main impact is not on the elasticity estimates, but on the constant and the innovation effect estimates.

IV estimation is carried out with conventional instruments. Labour and materials are instrumented, in a GMM framework, with their levels lagged two periods at each cross-section. The number of lags used can be increased without important changes. The variable capital plus utilization of capacity is instrumented using the capital growth rate at t-1. Notice that this is a valid instrument under the assumption that capital is a predetermined variable, which can be considered as taking in addition utilization of capacity as endogenous. The Sargan test of overidentifying restrictions points to the validity of the instruments. IV estimation increases all coefficients, but relatively a bit more the coefficient on materials and the coefficient on capital. Precision, however, is low. Returns to scale tend now to be increasing (elasticity of scale is 1.08 at the estimate which uses individual prices). The estimate which uses individual prices seems now to be more sensible, providing mainly a better account of the impact of innovation. From here on we will use individual prices.

We conclude that conventional estimators in differences seem to give not bad estimates when used with enough quality data And slightly better estimates if firm-level prices are available. However, neither the OLS estimates nor the IV estimates are fully convincing. The IV estimate is probably the closest to reliable values, but quite imprecise. We then turn to the other alternatives.

Tables B1 and B2 in Appendix present results of estimating the reduced forms of both equations. Table B1 shows regressions of the output on capital, utilization of capacity, wages, the price of materials and the three shifters.Table B2 presents the results of estimating the reduced form for cost, by regressing the average cost measure on capital, utilization of capacity, wages, the price of materials and the three shifters. Both tables compute all the elasticities according to the formulas of Section 2, assuming a price elasticity of demand equal to 5 (an arbitrary sensible value in the absence of any estimate for this elasticity[3]). Standard errors are computed according to the delta method.

In summary, the reduced form for output seems to work well with regard to the capital and the utilization of capacity coefficient estimates. But, unexpectedly, the price coefficients cannot be estimated by OLS. Interestingly enough, the instruments which work in prac-

[3] One of the problems of these preliminary estimates is that, in the absence of a reliable estimate on the coefficients via the two reduced forms, we cannot assess the elasticity of demand (that is, the ratio between the coefficients obtained in the two forms). This is the reason we report estimated elasticities under the assumption of a conjectured elasticitcity of 5

tice are likely to be correlated with important "shadow" price changes. The replacement of input quantities by prices has had the effect of lessening the problem of estimating a sensible coefficient for capital, but observed prices cannot be considered uncorrelated with the disturbances remaining in the equation. In addition, these estimates only give a long run elasticity by about 0.85. By the contrary, in the cost regressions OLS tends to work, with a partial exception for the variable capital. Capital is not significant, but utilization of capacity clearly gets the right sign and magnitude. The likely diagnosis is that the errors in variables problem in the capital variable is exacerbated in this equation (in what follows, we use the coefficient on the utilization of capacity or the restricted variable to compute the elasticities). The cost regressions seem to suggest that the cost relationship is really a reduced form with less problems that the ones found in the apparently similar production function form. Here it is not clear that IV reach an improvement. In fact, IV tend to decrease the coefficient on capital. OLS estimates are robust to a series of changes. In addition, the elasticity of scale is 0.9.

Table 2 shows the results of the non-linear GMM joint estimation of both equations. Here both the input elasticities and the elasticity of demand are simultaneously estimated. The method applied and the instruments used are as explained in Section 4. Results are good. Firstly, all the parameters which enter linearly have sensible coefficients. In particular, process innovation and utilization of the utilization of capacity variables have the right impacts. The shifters and margin indicators work. In addition, the parameters of interest are well estimated: returns to scale are 0.9, the value added elasticity of capital is high (0.44) and the model estimates a sensible η value (3.56).

Tables 3 and 4 present the estimates for the sample split in two type of firms, large and small, and in 10 industries respectively. Table 3 makes clear that the model works very well in the big firms: constant returns to scale are accepted, capital obtains a sensible elasticity (0.35) and the elasticity of demand with respect to price is estimated at 4.8. The estimate for the small firms shows however that it remains some specification work to be done: elasticity of capital seems clearly upwardly biased. The model applied to firms grouped in 10 industries give promising results, even if it makes again apparent that the elasticity of capital is probably biased.in most of the estimates. An additional split of the sample in firms belonging to high technology and low technology sectors gives results very similar to the whole sample.Further explorations have shows that the model is robust to simple controls as the way of computing capital (using or not lagged investment), the balanced/unbalanced character of the sample, the years used in estimation and the cleaning of extreme values. Other trials have made clear that the results are also robust to facts as outsourcing, the exit of firms or the number of years in sample. It remains to explore further the validity of the capital instrument (the used cost of capital), the impact of the errors in variables problem and possible sample selection biases.

5. Conclusion.

This paper has carried out a preliminary exploration of the use of reduced forms to estimate the parameters of microeconomic production functions. These reduced forms employ information on the demand relationship and the pricing of the firms. Estimates use a rich data set which includes the firm-level changes in the price of the output and in the prices paid by the inputs, the introduction of process and product innovations and information on demand shifters. The paper provides three type of estimates: direct conventional estimates of the production function, assuming a fixed input, capital, and two variable inputs, labour and materials; a production and an (average) cost reduced form equations in terms of the fixed input and the prices of the variable inputs, including demand and margin shifters, and a joint non-linear GMM estimation of the output and cost equations. Results are highly promising, even though if some questions remain to be addressed.

The main results are as follows. Conventional IV estimates applied to equations in first differences do not give bad results, although quite imprecise. The use of individual prices seems to matter, although does not change significantly elasticities. The reduced form for output provides good estimates for the coefficient on capital but, rather unexpectedly, prices have to be instrumented with variables close to shadow price changes. On the contrary, the reduced form for average cost produces sensible estimates for the coefficient on prices, but capital is not significant and utilization of capacity is needed to produce good estimates. The joint estimation of boh equations give highly sensible results, even if it remain two main worries about present results: decreasing returns to scale and a too high capital elasticity value in small fims. Three explanations to check thoroughly are the validity of the user cost of capital instrument, the errors in variables impact and possible selection biases.

The interest of the presented method is that it reduces the need for assumptions about the unobserved efficiency and seems to give sensible estimates of rts, input elasticicities and elasticity of demand. In particular, the elasticity of demand can be exploited in many interesting ways: output effects of cost changes (e.g. process innovations), approximation of welfare gains and loses etc.

Data Appendix:

All employed variables come from the information furnished by firms at the survey ESEE (Encuesta Sobre Estrategias Empresariales), a firm level panel survey of Spanish manufacturing starting in 1990, sponsored by the Ministry of Industry). The unit surveyed is the firm, not the plant or establishment, and some firms closely related answer as a group. At the beginning of this survey, firms with fewer than 200 workers were sampled randomly by industry and size strata, retaining 5%, while firms with more than 200 workers were all requested to participate, and the positive answers represented more or less a self-selected 60%. To preserve representation, samples of newly created firms were added to the initial sample every subsequent year. At the same time there are exits from the sample, coming from both death and attrition. The two motives can be distinguished and attrition was maintained to sensible limits. Composition in terms of time observations of the unbalanced panel sample employed here is shown in Table A.1. Table A.2 provide descriptive statistics and Table A.3 details the industry breakdown.

Definition of variables

Advertising: Firm's advertising expenditure deflated by the consumer price index.

Average cost: Total firm' costs divided by output.

Capital : Capital at current replacement values is computed recursively from an initial estimate and the data on current firms' investments in equipment goods (but not buildings or financial assets), actualised by means of a price index of capital goods, and using sectoral estimates of the rates of depreciation. Real capital is then obtained by deflating the current replacement values.

Hours per worker: Normal hours of work plus overtime minus lost hours per worker.

Industry dummies: Eighteen industry dummies.

Industry price decrease: Dummy variable that takes the value 1 when the firm reports an own-price decrease which has been motivated by a reduction of prices of competitors in its main market.

Industry prices: Industry indices computed for 114 sectors and assigned to the firms according to their main activity.

Labour: Number of workers multiplied by hours per worker.

Market dynamism: Weighted index of the market dynamism reported by the firm for the markets in which it operates. The index can take the values $0<d<0.5$ (slump), $0.5<d<1$ (expansion) and $d=0.5$ (stable markets). Included in regressions in differences from 0.5.

Materials: Intermediate consumption deflated by the price of materials.

Output: Goods and services production. Sales plus the variation of inventories deflated by the firm's output price index.

Price of materials: Paasche-type price index computed starting from the percentage variations in the prices of purchased materials, energy and services reported by the firms. Divided by the consumer price index except when used as a deflator.

Price of the output: Paasche type price index computed starting from the percentage price changes that the firm reports to have made in the markets in which it operates.

Product innovation: Dummy variable that takes the value 1 when the firm reports the accomplishment of product innovations.

Process innovation: Dummy variable that takes the value 1 when the firm reports the introduction of a process innovation in its productive process.

Utilization of capacity: Yearly average rate of capacity utilization reported by the firm.

User cost of capital: Weighted sum of the cost of the firm values for two types of long-term debt (long-term debt with banks and other long-term debt), plus a common depreciation rate of 0.15 and minus the rate of growth of the consumer price index.

Wage: Firm's hourly wage rate (total labour cost divided by effective total hours of work). Divided by the consumer price index.

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Table 1 Conventional production function estimates[1]

Dependent variable: Output[2] Sample period: 1992-1999 Method of estimation[3]		OLS	OLS	IV	IV
Independent variables					
	Constant	0.015 (0.002)	0.008 (0.002)	0.006 (0.009)	-0.003 (0.010)
	Process innovation dummy	0.016 (0.004)	0.012 (0.003)	0.013 (0.004)	0.007 (0.004)
	Capital+Utilization of capacity	0.066 (0.012)	0.069 (0.011)	0.177 (0.124)	0.210 (0.128)
	Labour	0.277 (0.027)	0.289 (0.026)	0.327 (0.167)	0.328 (0.174)
	Materials	0.429 (0.022)	0.43 (0.022)	0.577 (0.078)	0.593 (0.080)
	Time dummies Industry dummies	included	included	included	included
Statistics					
	Instruments			Capital growth rate at t-1 Labour and materials t-2 lagged levels at each cross-section	
	Sigma	0.108	0.107	0.120	0.121
	Residuals' fisrt order correlation[4]	(-8.4)	(-8.5)	(-7.7)	(-8.0)
	Residuals' second order correlation[4]	(-1.6)	(-2.0)	(-0.3)	(-0.3)
	Sargan test (degrees of freedom)			15.5 (14)	17.2 (14)
	No. of firms	1,408	1,408	1,408	1,408
	No. of observations	5,971	5,971	5,971	5,971
Elasticities					
	Returns to scale	0.772	0.788	1.081	1.131
	Value added elasticities:				
	Capital	0.191	0.193	0.351	0.390
	Labor	0.809	0.807	0.649	0.610

[1]All non-dummy variables in (log) growth rates.
[2]First and third columns deflated by individual prices, second and fourth columns deflated by industry prices.
[3]Robust standard errors in parentheses.
[4]Arellano-Bond test value.

Table 2
Estimated parameters of the production and cost functions
Joint nonlinear GMM estimation

	Variable	Parameter estimate	Standard error[1]
Production function	Constant	0.071	0.018
	Process innovation	0.019	0.003
	Market dynamism	0.097	0.001
	Advertising	0.014	0.002
	Product innovation	-0.002	0.001
	Utilization of capacity	0.176	0.004
Cost function	Constant	0.009	0.003
	Process innovation	-0.009	0.001
	Market dynamism	-0.024	0.001
	Advertising	0.007	0.001
	Product innovation	0.008	0.001
	Utilization of capacity	-0.040	0.001
Elasticities	Capital	0.125	0.045
	Labor	0.159	0.026
	Materials	0.627	0.049
	η	3.555	0.961
Parameter functions:			
	Returns to scale	0.912	0.057
Value added elasticities	Capital	0.440	0.099
	Labor	0.560	0.099
Sample period		1991-99	
No. of firms		1,408	
No. of observations		7,379	

[1] First step standard errors, robust to arbitrary autocorrelation over time and heteroskedasticity across firms.

Table 3
Estimated parameters of the production and cost functions
Joint nonlinear GMM estimation: Results by firm size

		More than 200 workers		Up to 200 workers	
	Variable	Parameter estimate	Standard error[1]	Parameter estimate	Standard error[1]
Production function	Constant	0.092	0.036	0.044	0.014
	Process innovation	0.028	0.010	0.017	0.003
	Market dynamism	0.066	0.016	0.107	0.002
	Advertising	0.024	0.007	0.011	0.001
	Product innovation	-0.004	0.002	0.002	0.001
	Utilization of capacity	0.306	0.038	0.139	0.001
Cost function	Constant	0.009	0.007	0.012	0.004
	Process innovation	-0.014	0.002	-0.005	0.002
	Market dynamism	-0.020	0.003	-0.024	0.001
	Advertising	0.012	0.001	0.006	0.001
	Product innovation	0.008	0.001	0.010	0.001
	Utilization of capacity	-0.073	0.008	-0.031	0.001
Elasticities	Capital	0.106	0.145	0.160	0.057
	Labor	0.200	0.045	0.116	0.027
	Materials	0.664	0.08	0.551	0.081
	η	4.787	1.32	2.000	0.801
Parameter functions:					
	Returns to scale	0.970	0.155	0.826	0.093
Value added elasticities	Capital	0.346	0.319	0.579	0.109
	Labor	0.654	0.319	0.421	0.109
Sample period		1991-99		1991-99	
No. of firms		464		944	
No. of observations		2,319		5,060	

[1] First step standard errors, robust to arbitrary autocorrelation over time and heteroskedasticity across firms.

Table 4
Estimated parameter functions of the production and cost functions
Joint nonlinear GMM estimation: Results by industries

Industry	Returns to scale[1]		Value added elasticities[1] Capital	Labor		η^1		No. of firms
1. Metals and metal products	1.006	(0.112)	0.339	0.661	(0.116)	9.703	(7.982)	168
2. Non-metallic minerals	0.931	(0.524)	0.699	0.301	(0.164)	0.666	(0.594)	108
3. Chemical products	0.970	(0.226)	0.669	0.331	(0.208)	1.264	(0.930)	173
4. Agric. and ind. machinery[2]	0.820	(0.229)	0.721	0.279	(0.206)	4.845	(3.562)	73
5. Data-proc. and electrical goods	0.915	(0.078)	0.429	0.571	(0.997)	61.696	(133.02)	126
6. Transport equipment	1.068	(0.138)	0.501	0.499	(0.249)	13.442	(12.174)	88
7. Food, drink and tobacco	0.798	(0.118)	0.576	0.424	(0.252)	2.662	(2.126)	234
8. Textile, leather and shoes	1.123	(0.129)	0.559	0.441	(0.124)	5.438	(3.762)	214
9. Timber and furniture[3]								91
10. Paper and printing products[2]	0.742	(0.176)	0.407	0.593	(0.209)	1.630	(1.148)	101

[1]First step standard errors in parenthesis, robust to arbitrary autocorrelation over time and heteroskedasticity across firms.
[2]Coefficient on utilization of capacity constrained to the same value than capital elasticity.
[3]Estimation does not converge to positive values of the elasticities.

Table A1. Sample detail

N^o of years in sample	N^o of firms	Observations
3	230	690
4	215	860
5	204	1020
6	150	900
7	115	805
8	143	1144
9	142	1278
10	209	2090
Total	1408	8787

Table A2. Variable descriptive statistics

	Mean	St. dev	Min	Max
Dependent Variables				
Output	0.031	0.239	-2.6	2.4
Average cost	0.021	0.154	-1.2	1.1
Explanatory Variables				
Advertising	0.023	0.903	-2.0	2.0
Capital	0.081	0.313	-2.1	7.3
Hours per worker	-0.001	0.065	-1.7	1.7
Industry price decrease	0.058	0.234	0	1
Industry prices	0.022	0.034	-0.21	0.4
Labour	-0.008	0.190	-2.8	1.7
Market dynamism	0.504	0.320	0	1
Materials	0.021	0.350	-3.3	5.4
Price of materials	0.035	0.060	-0.5	0.7
Price of the output	0.014	0.056	-0.7	0.7
Process innovation	0.332	0.472	0	1
Product innovation	0.266	0.442	0	1
User cost of capital	0.135	0.046	0.1	0.4
Utilization of capacity	0.001	0.191	-2.3	2.9
Wage	0.054	0.190	-1.5	2.4
Industry dummies				
Ferrous and non-ferrous metals	0.022	0.146	0	1
Non-metallic mineral products	0.075	0.263	0	1
Chemical products	0.071	0.256	0	1
Metal products	0.098	0.298	0	1
Agricultural and ind. machinery	0.053	0.225	0	1
Office and data processing machin.	0.009	0.093	0	1
Electrical goods	0.076	0.264	0	1
Motor vehicles	0.045	0.207	0	1
Other transport equipment	0.020	0.138	0	1
Meats, meat preparation	0.031	0.174	0	1
Food products and tobacco	0.117	0.321	0	1
Beverages	0.021	0.143	0	1
Textiles and clothing	0.116	0.321	0	1
Leather, leather and skin goods	0.032	0.176	0	1
Timber, wooden products	0.065	0.246	0	1
Paper and printing products	0.073	0.260	0	1
Rubber and plastic products	0.053	0.224	0	1
Other manufacturing products	0.025	0.155	0	1

Table A3. Industry definitions and equivalences

	Industry breakdown		ESEE clasiffication
1	Ferrous and non-ferrous metals and metal products	1+4	Ferrous and non-ferrous metals + Metal products
2	Non-metallic minerals	2	Non-metallic minerals
3	Chemical products	3+17	Chemical products + Rubber and plastic products
4	Agricultural and ind. machinery	5	Agricultural and ind. machinery
5	Office and data-processing machines and electrical goods	6+7	Office and data processing machin. + Electrical goods
6	Transport equipment	8+9	Motor vehicles + Other transport equipment
7	Food, drink and tobacco	10+11+12	Meats, meat preparation + Food products and tobacco + Beverages
8	Textile, leather and shoes	13+14	Textiles and clothing + Leather, leather and skin goods
9	Timber and furniture	15	Timber, wooden products
10	Paper and printing products	16	Paper and printing products

Table B1. Production function estimates[1]

Dependent variable: Output					
Sample period: 1991-1999					
Method of estimation[2]		OLS	IV	IV	IV[3]
Independent variables					
	Constant	0.006 (1.5)	0.033 (4.3)	0.091 (4.4)	0.084 (3.9)
	Process innovation dummy	0.026 (4.8)	0.026 (4.7)	0.020 (3.4)	0.028 (4.2)
	Capital	0.127 (6.0)	0.130 (5.7)	0.135 (5.8)	
	Utilization of capacity	0.189 (7.4)	0.196 (8.1)	0.202 (8.2)	
	Capital+Utilization of capacity				0.189 (7.1)
	Wage	0.137 (4.5)	-0.324 (-2.9)	-0.366 (-3.3)	-0.356 (-2.9)
	Materials' price	-0.026 (-0.5)	-0.073 (-1.3)	-1.70 (-3.0)	-1.759 (-2.9)
	Market dynamism	0.104 (11.8)			0.094 (7.8)
	Advertising	0.014 (4.1)	0.015 (3.7)	0.016 (3.8)	0.017 (3.5)
	Product innovation dummy	-0.000 (-0.1)	-0.001 (-0.2)	-0.002 (-0.3)	-0.002 (-0.3)
	Time dummies	included	included	included	included
	Industry dummies				
Statistics					
	Instruments		Hours per worker	Hours per worker Industry price decrease	Hours per worker Industry price decrease Capital growth rate
	Sigma	0.157	0.170	0.184	0.176
	Residuals' fisrt order correlation[4]	0.003 (-2.8)	-0.017 (-4.1)	-0.008 (-3.4)	-0.006(-2.930)
	Residuals' second order correlation[4]	0.004 (-1.3)	-0.001 (-1.5)	-0.005 (-1.8)	-0.005 (-1.83)
	No. of firms	1,408	1,408	1,408	1,408
	No. of observations	7,379	7,379	7,379	5,971
Elasticities (assuming $\eta = 5$)[5]					
	Capital			0.051 (0.013)	0.070 (0.017)
	Labor			0.138 (0.023)	0.132 (0.024)
	Materials			0.641 (0.102)	0.653 (0.105)
	Short run elasticity			0.779 (0.080)	0.786 (0.082)
	Long run elasticity			0.830 (0.090)	0.856 (0.097)
	Value added elasticities:				
	Capital			0.269 (0.069)	0.346 (0.085)
	Labor			0.731 (0.124)	0.654 (0.116)

[1]All non-dummy variables in (log) growth rates.
[2]T-ratios in parentheses computed from robust standard errors.
[3]Sample period 1992-1999.[4]Arellano-Bond test value.[5]Robust standad errors in parentheses.

Table B2. Cost function estimates[1]

Dependent variable: Average cost Sample period: 1991-1999 Method of estimation[2]		OLS	IV	IV	OLS	OLS
Independent variables						
	Constant	0.004 (1.5)	0.007 (2.6)	0.005 (1.3)	0.003 (1.0)	0.005 (2.0)
	Process innovation dummy	-0.012 (-3.6)	-0.011 (-3.2)	-0.011 (-3.3)	-0.011 (-3.2)	-0.008 (-2.8)
	Capital	0.001 (0.1)			0.001(0.2)	0.002 (0.3)
	Utilization of capacity	-0.042 (-3.6)			-0.042 (-3.6)	-0.047 (-3.9)
	Capital+Utilization of capacity		-0.041 (-3.6)	-0.039 (-3.5)		
	Wage	0.108 (6.5)	0.108 (6.5)	0.169 (5.2)	0.108 (6.5)	0.109 (6.6)
	Materials' price	0.386 (8.6)	0.390 (8.7)	0.347 (5.0)	0.382 (8.4)	0.387 (8.6)
	Market dynamism	-0.024 (-3.7)	-0.024 (-3.7)	-0.023 (-3.5)	-0.024 (-3.7)	
	Advertising	0.005 (2.2)	0.006 (2.4)	0.006 (2.4)	0.005 (2.1)	
	Product innovation dummy	0.008 (2.4)	0.008 (2.4)	0.008 (2.4)	0.009 (2.5)	
	Time dummies	included	included	included	included	included
	Industry dummies				included	
Statistics						
	Instruments		User cost of c U. of capacity	User cost of c U. of capacity w, p_M lagged levs.		
	Sigma	0.106	0.106	0.106	0.106	0.106
	Residuals' fisrt order correlation[3]	-0.158 (-12.6)	-0.154 (-12.5)	-0.153 (-12.7)	-0.159 (-12.6)	-0.159 (-12.6)
	Residuals' second order correlation[3]	-0.010 (-1.7)	-0.012 (-1.7)	-0.013 (-1.8)	-0.012 (-1.7)	-0.009 (-1.5)
	No. of firms	1,408	1,408	1,408	1,408	1,408
	No. of observations	7,379	7,379	7,379	7,379	7,379
Elasticities (assuming $\eta = 5$)[3]						
	Capital	0.071 (0.020)	0.069 (0.020)	0.064 (0.020)	0.071 (0.020)	0.078 (0.021)
	Labor	0.182 (0.013)	0.182 (0.013)	0.275 (0.027)	0.183 (0.014)	0.183 (0.013)
	Materials	0.648 (0.037)	0.651 (0.037)	0.566 (0.063)	0.645 (0.038)	0.648 (0.037)
	Short run elasticity	0.830 (0.025)	0.832 (0.025)	0.842 (0.036)	0.828 (0.026)	0.831 (0.025)
	Long run elasticity	0.901 (0.030)	0.901 (0.029)	0.906 (0.037)	0.899 (0.030)	0.909 (0.030)
	Value added elasticities: Capital	0.281 (0.081)	0.275 (0.079)	0.189 (0.059)	0.281 (0.081)	0.298 (0.079)
	Labor	0.719 (0.053)	0.725 (0.052)	0.811 (0.079)	0.719 (0.053)	0.702 (0.051)

[1]All non-dummy variables in (log) growth rates.

[2]T-ratios in parentheses computed from robust standard errors.

[3]Arellano-Bond test value.

[4]Robust standad errors in parentheses.